QUADRANT ENGINEERING INC.

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June 18, 1990

Scientific Officer
Office of Naval Research
Attn: Frank Herr, Code 1121RS
Ref: Contract N00014-90-C-0108
800 North Quincy Street
Arlington, VA 22217-5000

Dear Dr. Herr:

Enclosed is a completed form DD-250 for your approval of a progress payment in the amount of $8,333.00. My understanding is that your approved copy of form DD-250 should be mailed to:

DCASMA Hartford
Attn: MOCAS
130 Darlin Street
East Hartford, CT 06108-3234

I have also enclosed one copy of an interim report which describes progress that has occurred since the contract went into effect on 01 May 1990.

Sincerely yours,

Calvin T. Swift

lk
encl.

55 Cherry Lane • Amherst, Massachusetts 01002

QUADRANT TECH NOTE #90–1

June 15, 1990

Azimuthal Resolution Degradation Due to Ocean Surface Motion in Focused Arrays and SARs

JAMES B. MEAD

Project Engineer

During the meeting at WHOI (5–18–90), a discussion of the ability of the focused array to simulate the R/v ratios typical of airborne/spaceborne SARs arose. In particular, we questioned the ability of the focused array to yield the same azimuthal resolution, ρ, as the SAR. Neglecting the effects of orbital motion, the azimuthal resolution of a SAR imaging a time–varying target is given by [1,2]

$$\rho = \frac{N\lambda R}{2v}\left(\frac{1}{T^2} + \frac{1}{N^2\tau^2}\right)^{1/2} \tag{1}$$

where

N is the number of looks

$\frac{R}{v}$ is the range to velocity ratio, a fixed quantity in most SAR applications,

λ is the radar wavelength,

T is the time used to form an image (integration time), and

τ is the decorrelation time of the pixel being imaged.

Letting $N = 1$ (throughout this discussion) for $T \ll \tau$, ρ reduces to $\frac{\lambda R}{2vT}$ which for $vT = L_{array}$ can be shown to reduce to the conventional SAR resolution $\rho = D/2$ where D is the width of the physical antenna in the along track direction. For $T \gg \tau$, ρ reduces to $\frac{\lambda R}{2v\tau}$ where $v\tau$ may be thought of as an effective aperture length $L_{effective}$. Thus, for rapidly decorrelating targets, $L_{effective}$ is short and the SAR resolution will degrade substantially from the optimal $D/2$ value.

It is possible to use a sequentially sampled focused array of fixed length, L_f, to simulate SARs having various R/v ratios, although the focused array integration time, T_f, is coupled to v through

$$v = L_f/T_f \; . \tag{2}$$

It is informative to recast equation (1) in terms of L_f and T_f, replacing the somewhat artificial quantity of velocity. Thus substituting (2) into (1) yields

$$\rho = \frac{\lambda R}{2L_f}\left(1 + \frac{T_f^2}{\tau^2}\right)^{1/2} \tag{3}$$

For $T_f \ll \tau$, ρ reduced to $\frac{\lambda R}{2L_f}$ which is consistent with the result I presented at the WHOI meeting. (I had $\frac{\lambda R}{L_f}$ which assumed a $\cos^{1.8}$ taper.)

For $T_f \gg \tau$, ρ reduces to $\frac{\lambda R}{2L_f}\left(\frac{T_f}{\tau}\right)$ which increases linearly with T_f. During our discussion at WHOI, we interpreted (3) as differing significantly from (1) for large integration times. Shown graphically in Figure 1, (1) is seen to converge to the limit $2R/v\tau$ for large T, while (3) increases as T_f for large T_f. Upon reflection, this should have struck us as unusual considering equation (1) and (3) are equivalent, provided (2) holds. This confusion results from the fact that (1) plotted in Figure 1 assures a fixed R/v while (3) has

$$R/v = \frac{RT_f}{L_f}\,. \tag{4}$$

A more informative way to compare (1) and (3) is to plot a family of curves for (1) at various R/v. In the table below, T_f is given for various values of R/v using (4), assuming $L_f = 10$ meters and $R = 1000$ meters.

R/v	T_f
.1	.001 s
1.0	.01 s
10.0	.10 s
100	1.0 s

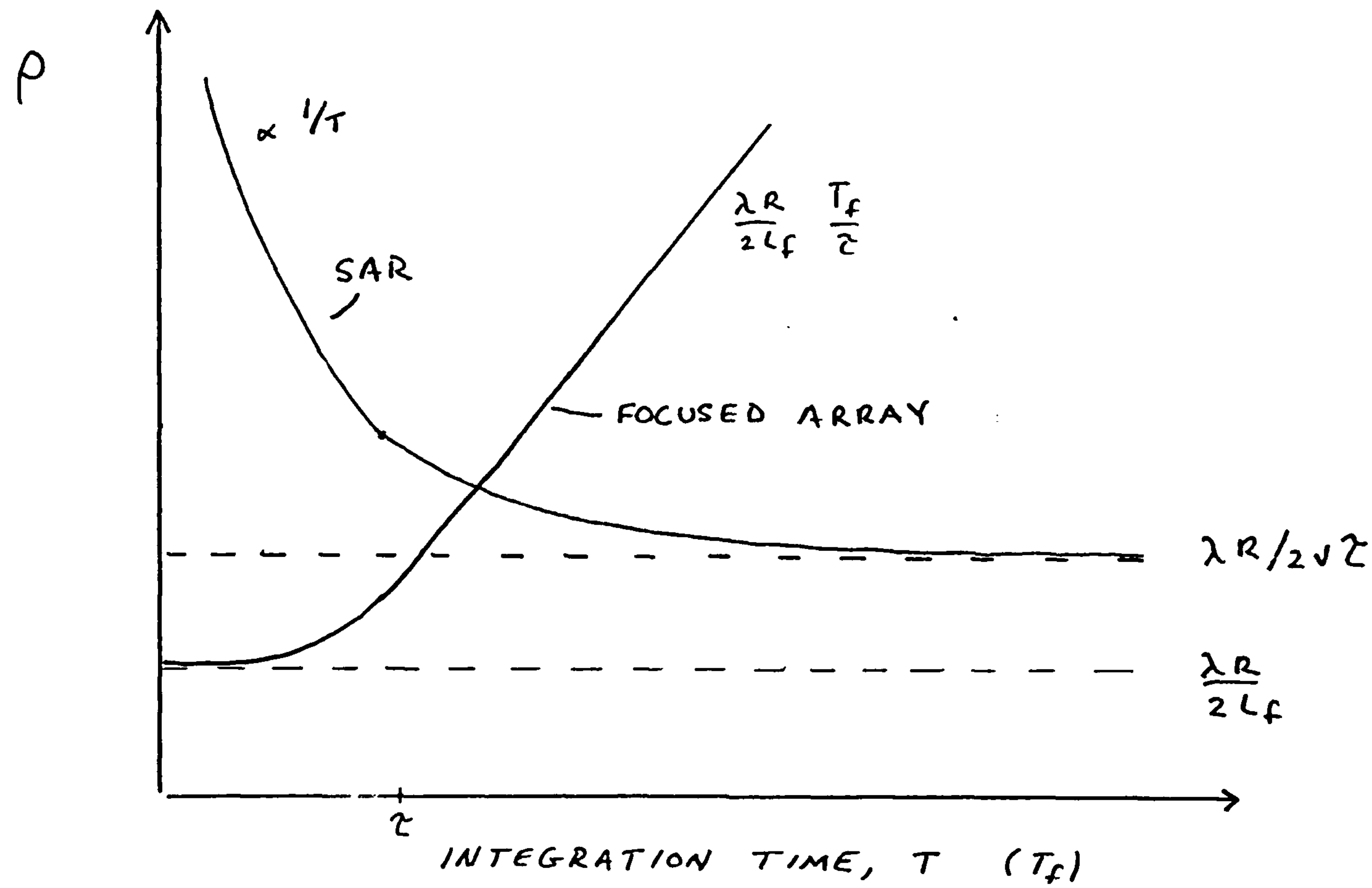

Fig. 1 – RESOLUTION, ρ, APPROACHES LIMIT DETERMINED BY SCENE DECORRELATION TIME, τ, FOR LARGE INTEGRATION TIME, T, (SAR); RESOLUTION INCREASES WITH T_f FOR LARGE T_f FOR FOCUSED ARRAY.

$$\rho = \frac{\lambda R}{2v}\left(\frac{1}{T^2} + \frac{1}{\tau^2}\right)^{1/2} \qquad \text{SAR}$$

$$\rho = \frac{\lambda R}{2L_f}\left(1 + \left(\frac{T_f}{\tau}\right)^2\right)^{1/2} \qquad \text{FOCUSED ARRAY.}$$

In Figure 2, a plot of (1) with R/v as a parameter, along with (3), shows that (1) and (3) are indeed equivalent when T_f is chosen to match R/v. In this plot, I have assumed $D = 100\ \lambda$, ($\beta = .01$ radians) and $\tau = .1$ s. It is evident that a focused array of fixed length may be used to study the effect of varying R/v and will give the same result as an airborne SAR.

Equation (1) becomes more complicated if the effects of orbital acceleration are included. Rufenach and Alpers [2] give the complete expression as

$$\rho = \frac{N\lambda R}{2v\tau}\left[1 + \frac{1}{N^2}\left\{\left(\frac{T}{\tau_s}\right)^2 + \left(\frac{\pi}{\lambda}T^2\hat{a}_r(x_0)\right)^2\right\}\right]^{1/2} \tag{5}$$

where

$$\begin{aligned} \hat{a}_r(x_0) &= \text{the orbital acceleration of the ocean waves} \\ \hat{a}_r(x_0) &= \hat{\varsigma}_0\hat{\omega}^2 g(\theta,\phi)\cos(\hat{k}_x x_0 + \delta) \end{aligned}$$

and

$$\begin{aligned} g(\theta,\phi) &= \text{geometric factor (=1 for azimuthally traveling waves)} \\ \hat{\varsigma}_0 &= \text{ocean wave amplitude} \\ \hat{\omega} &= \text{ocean wave angular frequency} \\ k_x &= \text{ocean wave number} \\ x_0 &= \text{azimuthal position} \\ \delta &= \text{fixed phase term} \end{aligned}$$

For typical ocean and SAR conditions, the following inequality holds:

$$\left(\frac{T}{\tau_s}\right)^2 \ll \left(\frac{\pi}{\lambda}\hat{a}_r T^2\right)^2 \tag{6}$$

Thus, the effects of orbital motion most likely will dominate image degradation. As before, there is no fundamental difference between the real SAR and the focused array, provided

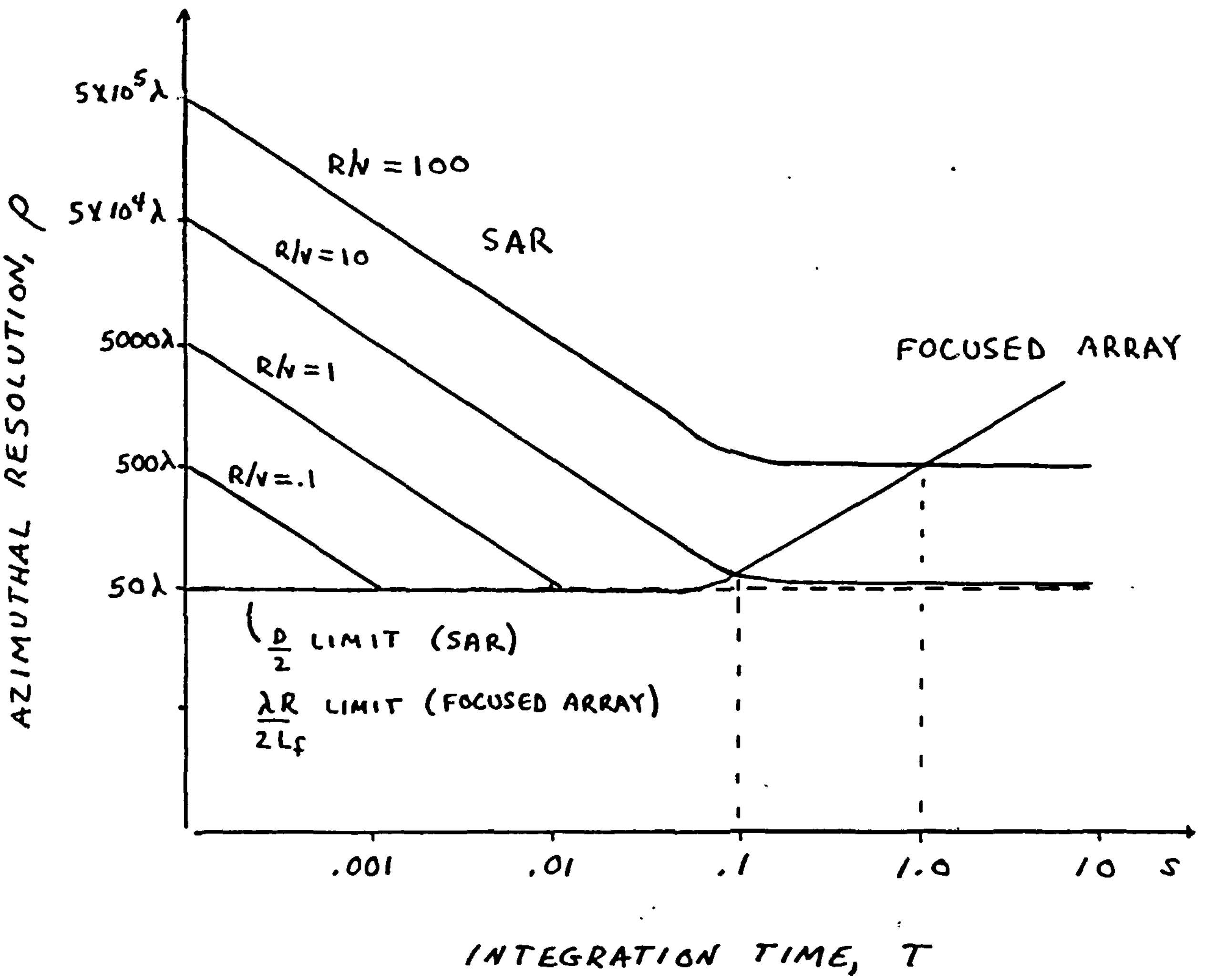

FIGURE 2 — COMPARISON OF EQ. (1) AND (3) SHOWING EQUIVALENCE WHEN (2) IS SATISFIED. ($D = 100\lambda$; $\tau = .1\,s$; $R = 1000\,m$ FOR FOCUSED ARRAY; $L_f = 10\,m$).

the resolution does not degrade beyond the maximum achievable by the focused array. This maximum value will occur when ρ is equal to the azimuthal swath width, i.e., $\rho_{max} \cong \frac{\lambda R}{D_{eff}}$ where D_{eff} is the effective azimuthal width of the individual radiating element in the focused array (approximately 2λ in the proposed design). Equating (5) to ρ_{max} and solving for $(R/v)_{max}$ and assuming the term due to orbital motion dominates, gives

$$\left(\frac{R}{v}\right)_{max} = R\sqrt{\frac{2\lambda}{D_{eff} L_f \pi \hat{a}_r}} \tag{7}$$

For $R = 100$ m, $D_{eff} = .10$ m, $\lambda = .05$ m, ocean wave height = 1 meter and wave frequency $= .4\ s^{-1}$, $(\frac{R}{v})_{max} = 44$, which is lower than spaceborne SARs ($\frac{R}{v} \cong 120$) but is in the range of typical values for airborne SARs. It should be noted that this analysis is based on a monochromatic sea spectra, and is thus highly idealized. Thus (7) should be used to give a rough estimate of $(\frac{R}{v})_{max}$.

Although the focused array can be sampled to yield the same azimuthal resolution as the SAR, it is likely that the images generated by the focused array will not be identical to those produced by a SAR with the same azimuth resolution. For a true SAR, biases in the Doppler history of azimuthally traveling waves due to their along-track motion will cause shifts in their apparent position.. This will cause waves which are physically at one location to shift over several pixel widths in the image. The limited swath width of the focused array will prevent it from observing scattered power from waves falling outside the swath, thus such waves will not affect the image formed within the swath, as would happen in the SAR. Thus, it is likely that the focused array will not yield the same image as a SAR having the same resolution.

[1] Raney, R. K., "SAR Response to Partially Coherent Waves," IEEE Trans. Antennas and Prop., Vol. AP-28, No. 6, November 1980, pp. 777-787 (Eq. 39).

[2] Rufenach, C. L., Alpers, W. R., "Imaging Ocean Waves by Synthetic Aperture Radars with Long Integration Times," AP–29, No. 3, May 1981, pp. 422–428.